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Markets for tradable emission permits with fiscal competition

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Abstract

We model a non-cooperative energy tax setting game amongst countries who join an international market in which firms trade emission permits. Countries can auction a share of their permit endowment and issue the remainder for free to a representative firm. Each country's regulator has a double mandate consisting of obtaining tax and auction revenue without increasing firm's costs too much. Energy may be subsidized or taxed depending on the relative weight of the two objectives. We show how equilibrium taxes depend on the proportion of permits which is auctioned, on the total amount of permits in the market, on the allocation of permits across countries and on the number of participating countries. We also show how the creation of the market in a previously unregulated world changes energy taxation. Finally, we highlight that, despite the permit market being perfectly competitive, it does not achieve emission abatement in a cost-efficient way.

Keywords: tradable permits, fiscal competition, EU-ETS, Kyoto protocol.

JEL classification: Q48, Q52, H23, H73

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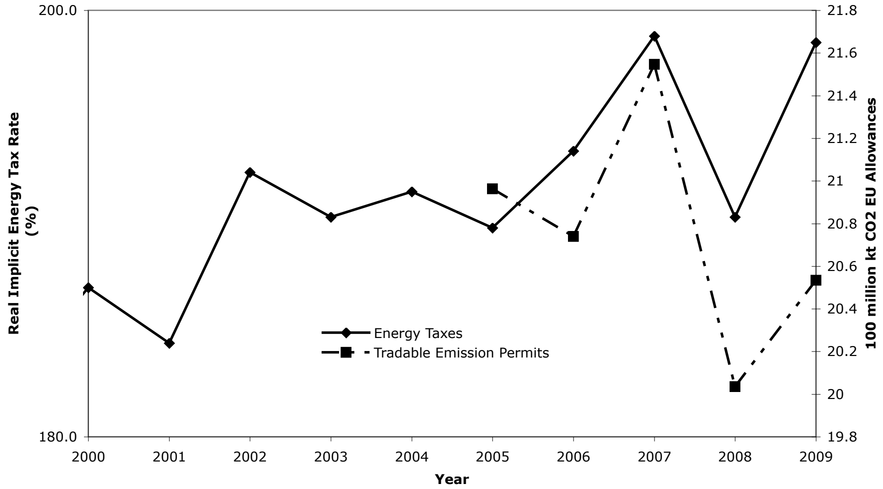
1 Introduction

A permit price of 30$ per ton of carbon dioxide roughly doubles the price of coal for the industry. Managing the cost borne by the firms constitutes a major concern for national governments when it comes to fiscal decisions regarding energy. Anecdotical evidence supports how topical was this policy issue with the implementation of the European Union Emission Trading Scheme (EU-ETS). For example, such a concern was behind Sweden and Denmark's July 2006 appeals to the European Commission for permission to cut their existing carbon taxes on the trading sector. After the implementation of the EU-ETS, those countries considered the co-existence of pre-existing carbon and energy taxes with emissions trading as double taxation which could jeopardize their competitiveness. This should come as not surprise given the documented fact that countries set their environmental policy strategically (Kellenberg, 2009, Fredrikkson and Millimet, 2002, Fredriksson et al., 2004).

Many countries are used to subsidizing energy production or consumption. For example, the OECD survey on *Environmentally Harmful Subsidies* (OECD, 2005) reports calculations made by the U.S. Department of Energy's Energy Information Administration (EIA). In 1999, the subsidies to the primary energy sector in the United States (based only on budgetary expenditures) amount to nearly USD 4 billion. Yet, energy taxes represent a non-negligible source of revenue for most countries. As of 2010, energy tax revenue amounted to 4.7% of the total tax revenue on average, for the EU-27, ranging from 2.8% in Norway to 9.4% in Bulgaria, according to Eurostat. They also account for a considerable share of total energy costs: in 2005, the share of taxes in oil prices borne by the industry was 4.3% in Belgium, 4.8% in Japan, 4.9% in the United States, 13.6% in Germany, 20.3% in the UK and 46.2% in Italy.[1]. While international cooperation on such taxes has so far failed on the political arena, major steps have been taken with the joint implementation of tradable emission permits (TEPs) international markets. On the one hand, a worldwide market for greenhouse gases under the Kyoto protocol came into force in February 2004. On the other hand, the EU-ETS organizes trading for permits on carbon dioxide emissions among industrial firms within the EU since January 2005. Countries are thus cooperating on these markets while at the same time they remain responsible for taxes on energy fuels, the main source of carbon dioxide emissions. Since energy taxes fall on polluting firms – the players in these international markets – we may expect energy taxes to have an impact on the TEP equilibrium price. As a consequence, countries may strategically manipulate energy taxation as a means to minor the costs borne by their domestic firms.

Figure 1 shows the recent evolution of average energy taxes in the EU, together with the total pollution permits traded in the EU-ETS market. This preliminary evidence suggests that the market size has an impact on the tax level. The objective of this paper is to provide a simple tax competition model that offers an explanation for this fact.

[1]Source: International Energy Agency, 2005.



Note: Implicit Energy Taxes are in Euro per ton of oil equivalent, deflated with cumulative percentage change. Source: "Taxation Trends in the European Union", European Commission, 2012. Tradable Permits are in 1000 emission units of Kt CO2 equivalent. Source: European Environment Agency.

Figure 1: Energy Taxes and Tradable Permits in the EU

We consider firms which burn fossils fuels for production and thus emit carbon dioxide. These emissions are regulated by a competitive international market for tradable permits. A proportion of the permits is freely given to the firms, while the remaining are auctioned by the governments. Energy taxes levied on fuel consumption are under the jurisdiction of national regulators, whose mandate combines firms' costs, energy tax revenue, and TEP-auction revenue. We distinguish between regulators which attach more weight to the former, or to the latter. We call them, respectively, *firm-oriented* and *revenue-oriented* regulators. Our analysis allows us to identify the externalities that a country's tax choice imposes upon the remaining countries via its impact on the TEP-market equilibrium.[2] Firstly, the tax base of other countries varies because the cost of energy changes, the so-called *fiscal externality*. Secondly, the net payments from national to foreign firms also change because the TEP price varies, the so-called *pecuniary externality*. We also highlight three effects which drive the strategic interaction amongst countries. We show that the higher the energy consumption, the higher the country's incentive to tax (*tax base affect*); if national firms' TEP demand is very responsive to the energy cost, taxation is discouraged (*permit-leakage effect*); finally, taxation is influenced by the net position of the country on the market for permits and by its market power (*terms of trade effect*). The combination of these effects allows us to understand how the design of market for permits affects equilibrium taxes. We pay attention to three issues: the total amount of permits issued in the market, the distribution of these permits among

[2]Our model shares this feature with other tax competition setups. A comprehensive survey is provided by Wilson, 1999.

the countries (countries' endowment), the number of countries involved in the market, and the introduction of a TEP-market in a previously unregulated world. Our analysis confirms the result obtained by Santore *et al.* (2001) that the international market for tradable permits does not lead to the minimization of total emission abatement costs. This contradicts the usual textbook wisdom and is due to the unequal Nash equilibrium tax rates which result from country heterogeneity (itself the result of firm asymmetry). Furthermore, we show that market outcome (and in particular the permit price) depends on whether the permits are grandfathered or auctioned.

Since the pioneering works of Dales (1968) and Montgomery (1972) the literature on tradable permits has followed many directions, some of them related to our subject of concern.[3] The interplay between distortive taxation and optimal environmental policy has been popularized under the (sometimes fuzzy) concept of *double dividend*. Goulder (1995) provides an authoritative taxonomy of this concept. Much progress in our understanding of this interaction has occurred. In particular, Babiker *et al.* (2003) use a CGE model to show that the interplay between carbon policies and pre-existing taxes can differ markedly across countries, depending on the levels of prior distortive taxes in an economy. Notably, they argue that climate policies under consideration will likely not provide a weak double dividend in a number of European countries. The fact that actual TEP markets diverge from the standard textbook has been addressed recently by Babiker *et al.* (2004), who emphasize the fact that the gains from trade can be outweighed by secondary costs associated with prior tax distortions and market imperfections, providing an illustration with the CGE model EPPA. In the same spirit, Copeland and Taylor (2005) use an international trade setting to show that the gains from trade can be ruined by terms of trade effects. This strand of literature, however, ignores the fact that country-level policies may react to the implementation of international climate policies.

The idea that country-level regulation may strategically interact with the market for TEPs has been little discussed in the literature, or it has been addressed in indirect and implicit ways (see Cropper and Oates (1992), Coggins and Swinton (1996), Bui, 1998).[4] There are some notable exceptions. The first, by Santore *et al.* (2001), examine the strategic behavior of state-level utility regulators in the context of the US federal trading system on sulfur oxide emissions. State-level regulators act independently of the federal authority by imposing pollution penalties on their own utilities, hence leading to an emissions trading scheme which is not cost-efficient. The second is an analysis of energy taxation and a TEP-market in a two-sector economy, by Eichner and Pethig (2009). The non-tradable sector's emission target is attained with tax regulation, while the tradable sector participates in the international TEP-market and may also be subject to energy taxation (tax rates may differ across sectors). This paper also shows the inefficiency of energy taxation (in the tradable

[3]The literature comparing the merits of policy instruments (prices versus quantities) is beyond the scope of our analysis. We do not compare instruments, we analyze the implications of adding a new instrument (tradable permits) on pre-existing ones (energy and carbon taxes).

[4]For example, Oates's book (2004) on environmental policy and fiscal federalism disregards this issue.

sector). In addition, they show that a permit-importing country has an incentive to tax, while a permit-exporting one faces a disincentive, a result which we also obtain in our setting. A more recent contribution by the same authors (Eichner and Pethig, 2010) models the interaction between international emissions trading and national green energy promotion policies. The finding that strategic energy taxation leads to cost-inefficient abatement has also been obtained by Hoel (2005) in a setup where international trade leads countries to set energy taxes which are not uniform across production sectors.

The remainder of the paper proceeds as follows. The next section sets out the model and preliminary results regarding the TEP-market and the main forces driving strategic tax setting. The effects of the total number of TEPs and the number of participating countries in equilibrium taxation are analyzed in Section 4, while section 5 is devoted to the comparison with autarky. We analyze the effect of firms' TEP-endowment and discuss how it can influence the efficiency of the TEP-market in section 6. Section 7 concludes. All the results are proved in the Appendix.

2 The model

We consider an economy composed of N countries where a global pollutant is regulated by an international market for tradable emission permits (TEP). Hence, our setting parallels the EU-ETS market. In addition, each country is responsible for its own national energy tax.

2.1 The firms

Each country, indexed by c, hosts a representative firm.[5] We consider cost minimizing firms which use a polluting input denoted by e_c (typically, fossil fuels). The production cost is $c(e_c)$, where e_c is the energy consumed by the firm in country c; we naturally assume that it is more costly to produce consuming less energy, i.e., $c'(e_c) < 0$, In addition, the firms bear an increasing cost to further decrease energy consumption: $c''(e_c) > 0$. By normalization, we assume that one unit of energy consumption yields one unit of pollution emission, which in turn corresponds to one polluting permit.[6] Firms take the price of energy, normalized to 1, as given. In the absence of regulation, the firm chooses a pollution level e^o such that $-c'(e^o) = 1$. In order to abate pollution below this unregulated level, the firm bears an abatement cost $C(e_c) = c(e_c) - c(e^o)$, respecting $C'(e_c) < 0 < C''(e_c)$.

Pollution is regulated with an international market for tradable emission permits (TEP) in which each firm is a price-taker.[7] We denote the price of permits by ρ. In

[5] The analysis would be unchanged if we supposed a continuum of price-taking firms in each country; see Bréchet and Peralta (2007) for such an analysis.

[6] For example, carbon dioxide emissions are strictly proportional to the carbon content of the fuels.

[7] This is natural assumption, since the EU-ETS market covers more than 14,000 installations over

addition, countries charge a unit energy tax t_c. Hence, the *regulated cost* of energy in country c is given by $p_c = 1 + t_c + \rho$.

The market for permits works as follows. The participating countries agree on a global amount of permits $\bar{E}$ and on a way to split it amongst countries. The amount of emission permits in country c is denoted by $\bar{e}_c$. Each country then issues a proportion $\alpha \in (0, 1)$ of these permits to the firms for free and auctions the remaining part, $(1-\alpha)$. Our parameter α thus measures the share of permits that are grandfathered.[8] In each country the representative firm thus faces the following cost minimization problem

$$\min_{e_c} \quad t_c e_c + \rho(e_c - \alpha\bar{e}_c) + C(e_c).$$

Hence, $e_c(p_c)$ is implicitly given by the first-order condition

$$-C'(e_c) = 1 + \rho + t_c = p_c, \tag{1}$$

and we have that

$$\frac{de_c}{dp_c} = e'_c = -\frac{1}{C''(e_c)} < 0, \tag{2}$$

hence, when the cost of energy increases, the firm pollutes less. We make two further assumptions on the demand for permits. Firstly, we assume that the demand is (weakly) convex, that is,

$$\frac{d^2 e_c}{dp_c^2} \geq 0$$

This assumption corresponds to the intuitive property that, as the regulated price of emissions increases, emissions decrease, but at a decreasing rate.[9] Secondly, we assume that the demand for permits is not too convex, in the sense that the semi-elasticity of permit demand

$$\eta(p_c) = -\frac{e'_c(p_c)}{e_c(p_c)} > 0$$

27 countries in the European Union.

[8]In the EU-ETS, free allocation ought to represent at least 95% of total allocation in the first phase (2005-2008), and at least 90% in the second phase (2008-2012). For an analysis of endogenous permits allocation, see *e.g.* Helm (2003) or Godal and Holtsmark (2010). For the EU-ETS, national allocations plans have been decided at the country level, but in close coordination with the EU Commission. See Ellerman *et al.* (2007) for an analysis of the whole procedure. See also the web site of the European Commission for up-to-date information on National Allocation Plans (*http://ec.europa.eu/environment*).

[9]Rewriting (2) as $-c''(e_c)\frac{de_c}{dp_c} - 1 = 0$, and differentiating it with respect to p_c, one gets

$$-\frac{d^2 e_c}{dp_c^2} C''(e_c) - \left(\frac{d_c^e}{dp_c}\right)^2 C'''(e_c) = 0,$$

and since the first term is negative, the second must be positive, so convexity of the demand amounts to imposing $C'''(e_c) \leq 0$. Assumptions on third order derivatives are common in the tax competition literature (Laussel and Le Breton, 1998, Peralta and van Ypersele, 2005).

is increasing with p_c. Notice that when p_c increases, e_c decreases and $(-e'(c))$ decreases as well. Our assumption of increasing semi-elasticity amounts to say that the former (first-order) effect dominates the latter. It may also be seen as an upper bound on the convexity of firm's permit demand.

2.2 The government

Because the market for tradable permits sets an emission cap in the global economy, the environmental quality is now exogenous to each country. So national energy taxes become useless for regulating polluting emissions.[10] As discussed in the introduction, the countries are concerned by the costs borne by the firms; however, excessive concern for these could bring energy taxation to excessively low levels, which might be a source of concern given that some countries rely on it as an important source of revenue. Indeed, the European Commission explicitly recognizes that "*Energy taxes (...) have been used purely as revenue raising instruments, originally without environmental purposes.*" (European Comission, 2012).

Consequently, we shall assume that the objective function of country c regulator is to maximize a weighted sum of energy tax revenue and permits auction revenue, net of firms production costs, the latter with a weight of $\gamma > 0$. Increasing the energy tax or the share of permits that are auctioned is revenue raising, but it is costly to the firms. So the regulator faces a trade-off. For the sake of exposition, let us characterize two regulator profiles. We shall refer to the case $\gamma > 1$ as the *firm-oriented regulator* and to the case $\gamma < 1$ as the *revenue-oriented regulator*.[11] The regulator of country c thus sets an energy tax $0 \leq t_c \leq \bar{t}$ so as to maximise

$$\max_{t_c} U_c = t_c e_c + (1-\alpha)\rho\bar{e}_c - \gamma\left(t_c e_c + \rho(e_c - \alpha\bar{e}_c) + C(e_c)\right). \qquad (3)$$

Notice that countries are asymmetric, except if they have the same emission endomwent.[12]

3 Preliminary results

In this section we introduce some preliminary results regarding the functioning of the TEP market, and the strategic effects of energy taxes in our setting.

[10]Actually, energy taxes can also be used for other sources of pollution rather than industrial CO_2 consumption (*e.g.*, automobile usage), so they could still serve the purpose of regulating *local* pollutants. We are thus making the simplifying assumption that the energy tax base is exclusively energy consumption by firms.

[11]The assumption of a double mandate for the regulator is usual in papers dealing with pollution regulation. For instance, Requate and Unold (2003) assume that the regulator minimizes the sum of firms' abatement costs and environmental damage.

[12]Notice that in the alternative setting without the representative firm, countries are not perfectly symmetric to the extent that the firms with the same technology do not necessarily have the same TEP-endowment. All the results go through as long as all the countries have the same total TEP-endowment. Please refer to Bréchet and Peralta (2007) for details.

3.1 Equilibrium in the market for tradable emission permits

Firms are price takers in the international TEP market. Each firm is endowed with $\alpha\bar{e}_c$ emission permits, and the regulator auctions the amount $(1-\alpha)\bar{e}_c$. Total permits supply in the TEP market is thus $\sum_{c=1}^{N}\bar{e}_c = \bar{E}$. Individual firm demand $e_c(p_c)$ is implicitly given by (1), hence the permits market clears when

$$\sum_{c=1}^{N} e_c(p_c) = \sum_{c=1}^{N} \bar{e}_c = \bar{E} \tag{4}$$

We show in the Appendix that there is a unique permit price that clears the market and that it is positive provided that the global emission cap is sufficiently restrictive.

National energy taxes have an impact on the TEP-market because they influence firms' energy consumption, and thus pollution. Totally differentiating (4), one obtains

$$\frac{d\rho(\mathbf{t},\bar{E})}{dt_c} = \rho_{t_c} \quad = \quad -\frac{e_c'(p_c)}{\sum_{j=1}^{N} e_j'(p_j)} < 0 \tag{5}$$

The intuition works as follows. If a country increases its tax rate on the energy input, firms in that country reduce their energy consumption, thus demanding less permits. *Ceteris paribus*, the aggregate demand for permits decreases and the equilibrium price must decrease to clear the market. One should note that

$$\frac{de_c}{dt_c} = e_c'(1+\rho_{t_c}) = e_c'\frac{\sum_{j\neq c} e_j'(p_j)}{\sum_{j=1}^{N} e_j'(p_j)} < 0$$

That is, if country c increases it energy tax, the equilibrium price of permits decreases, but still the cost of energy increases and the firms in that country pollute less. But as a consequence, the lower permit price leads to an increase in the emission level in all other countries in the economy, that is:

$$\frac{de_c}{dt_j} = e_c'\rho_{t_j} > 0,\ j \neq c$$

This means that every country potentially has some market power in the market for TEPs. It should be noticed that (5) can be rewritten as

$$\rho_{t_c} = -\frac{\eta_c e_c}{\sum_{j=1}^{N} \eta_j e_j},$$

from which it is clear that the impact of a given country's energy tax rate on the TEP price is greater the greater is that country's firm's demand for permits, on the one hand, and the (semi-)elasticity of this demand, on the other hand. If the representative firm reacts strongly to the increase in the energy cost, the country has a stronger market power. In the following subsection these effects will be further analyzed, and we will show how they interact in equilibrium.

3.2 The strategic effects of energy taxation

We solve for a Nash equilibrium in energy taxes. The regulator in country c chooses t_c so as to maximize its payoff defined by (3). Notice that each regulator's payoff depends on the tax choice of the other regulators *via* the permits price in equilibrium.

The first-order condition for the regulator's problem (3) in country c writes as follows

$$\underbrace{(1-\gamma)e_c(p_c)}_{\text{Tax base effect}} + \underbrace{t_c \frac{de_c(p_c)}{dt_c}}_{\text{Permit-leakage effect}} - \underbrace{\rho_{t_c}\left(\gamma(e_c(p_c) - \alpha\bar{e}_c) - (1-\alpha)\bar{e}_c\right)}_{\text{Terms of trade effect}} = 0 \quad (6)$$

The above expression identifies the determinants of tax setting by each country. As usual in tax competition games with terms-of-trade effects, the conditions for the quasi-concavity of the payoff functions are cumbersome (see, *e.g.*, Peralta and van Ypersele, 2005). Throughout the paper we are going to assume that (at least one) Nash equilibrium exists with tax rates defined by (6). There exists at least one class of cost functions (the quadratic one) which respects convexity of the abatement cost and increasing semi-elasticity of the TEP-demand where the unique Nash equilibrium is given by (6).[13]

The first-order condition (6) identifies three key equilibrium effects.

The *tax base effect:* the larger the energy consumption by the firm in country c, the higher the country's incentive to tax (as long as $\gamma < 1$). This is weighted down by γ, for an increase in the energy tax rate increases firms' cost. The tax base effect becomes negative for $\gamma > 1$, *i.e.* when the regulator gives more weight to firm's costs than to fiscal revenue.

The *permits leakage effect:* provided that the tax base decreases with the tax rate, taxation is discouraged when the tax rate is positive, and encouraged otherwise. The magnitude of this effect depends on the country's market power. To see this, notice that

$$\frac{de_c(p_c)}{dt_c} = (1 + \rho_{t_c})\, e_c'(p_c)$$

Hence, a higher market power lowers the sensitivity of the tax base to the tax rate, for the TEP price absorbs a greater share of the tax increase. The tax base and permit-leakage effect actually sum up to a Laffer curve, modified by $(1-\gamma)$.

The *terms of trade effect:* this effect stems from the fact that the TEP price decreases with the country's tax rate. When the representative firm buys emission permits (*i.e.* when it pollutes more than its endowment), and when the share of grandfathering increases (*i.e.* a decrease in $1-\alpha$), then the regulator benefits from a lower ρ

[13] In order to ensure concavity of the payoff functions in the quadratic case, one needs to assume further that $\gamma < \frac{2N}{N-1}$. Details available from the authors, upon request.

and has thus a higher incentive to tax. We shall refer to $(\gamma(e_c(p_c) - \alpha\bar{e}_c) - (1-\alpha)\bar{e}_c)$ as the *perceived importing position* of country c in the market for permits. When $\gamma = 1$, the regulator is a perfect agent of the firm, and the perceived importing position is equal to the actual one, *i.e.*, $e_c(p_c) - \bar{e}_c$. When the regulator only cares for tax revenue, then it acts *de facto* as a permit exporter, i.e., it has an interest to raise the permit price.[14]

It is also interesting to check how grandfathering changes the perceived permit import. When all permits are auctioned (with $\alpha = 0$), the perceived importing position is equal to $\gamma e_c(p_c) - \bar{e}_c$, while with total grandfathering ($\alpha = 1$), it is given by $\gamma(e_c(p_c) - \bar{e}_c)$. Hence, for a revenue-oriented (resp., firm-oriented) regulator, grandfathering increases (resp., decreases) the perceived importing position of a country. Grandfathering is thus an incentive to tax for a revenue-oriented and a disincentive to tax for a firm-oriented regulator. Giving more TEP to the firm for free decreases the firm's importing position but it also increases the country's supply of permits to auction in the market, the former carrying a weight of γ. Hence, the perceived importing position decreases only when $\gamma > 1$.

Straightforward manipulation of (6) defines implicitly the Nash equilibrium energy tax of country c as

$$\hat{t}_c = \frac{(1-\gamma)\hat{e}_c(p_c) - \hat{\rho}_{t_c}\left(\gamma(\hat{e}_c(\hat{p}_c) - \alpha\bar{e}_c) - (1-\alpha)\bar{e}_c\right)}{-(1+\hat{\rho}_{t_c})\hat{e}'_c(\hat{p}_c)} \tag{7}$$

Where $\hat{x}$ denotes the equilibrium value of the variable x.

4 The emission cap, the number of countries, and energy taxes

We now study the impact of the fundamentals of the TEP-market on energy taxes. In order to do so, we focus on symmetric countries, *i.e.*, we let $\bar{e}_c = \bar{e} = \bar{E}/N$, $\forall c$. We shall relax this assumption later. In this case it turns out that there exists a symmetric equilibrium where all countries set the same tax rate in equilibrium. With equal tax rates, energy prices are the same across countries, and so is energy consumption. Equilibrium in the permit market then yields $\hat{e}_c = \hat{e} = \bar{E}/N = \bar{e}$, $\forall c$. Given the symmetry of tax bases, we have that $\hat{\rho}_{t_c} = 1/N$. Let $\hat{\eta}$ be the semi-elasticity of TEP-demand evaluated at $\hat{p}_c = \hat{p}$, $\forall c$ which respects $e_c(\hat{p}) = \bar{E}/N$, $\forall c$. Straightforward simplification of (6) thus yields

$$\hat{t}_c = \hat{t} = \frac{1}{\hat{\eta}}(1-\gamma)\frac{1 - \frac{1-\alpha}{N}}{1 - \frac{1}{N}} \tag{8}$$

Obviously, in the symmetric equilibrium the representative firm in each country consumes exactly the TEP-endowment of the country. However, the *perceived importing*

[14] A similar argument is found in the capital tax competition literature. See De Pater and Myers (1994) and Peralta and van Ypersele (2005).

position of each country is equal to $\bar{e}((\alpha - 1)(1 - \gamma))$, which is equal to zero only when no permits are auctioned ($\alpha = 1$). With (however small) auctioning, the regulator perceives an exporting position when $\gamma < 1$, and an importing position otherwise. Indeed, when there is auctioning and the regulator is revenue-oriented, it gives a higher weight to permits endowment than to permits consumption, hence it behaves as an exporter. Conversely, a *firm-oriented regulator* ($\gamma > 1$) gives a higher weight to permits consumption, so it behaves as if permits were imported in equilibrium. Note also that the perceived importing or exporting positions of the regulators are both increasing in α, since giving more

We can now state our first result in the following proposition, which relates grandfathering and the regulator's mandate to energy taxation.

Proposition 1 *In the symmetric equilibrium,*

(i) *'firm-oriented regulators' subsidize energy, and the subsidy is increasing in the share of grandfathering,*

(ii) *'revenue-oriented regulators' tax energy, and the tax raises with the share of grandfathering;*

(iii) *the permit price increases in the former case, and decreases in the latter case, with the share of grandfathering.*

Proof. Straightforward derivation of (8), together with the fact that ρ is decreasing in tax rates. Also, it is obvious that when $\gamma > 1$, $\hat{t} < 0$. ■

The relative importance of each of the regulator's double mandate has a clear implication: when firm's costs are more important than fiscal and auction revenue, countries subsidize energy consumption, otherwise they tax it. Grandfathering creates incentive for further distortion: increasing subsidies or taxes, depending on whether regulators are firm- or revenue-oriented. This stems from the changed perceived importing position of the country as discussed in Subsection 3.2 above. Through its strategic effect on energy taxation, grandfathering also has an impact on the permit price. This is in contrast to the usual result in the literature that under perfect competition and in a static setting, the market outcome is independent of permits allocation.

We now turn to explore the effects of two main features related to the design of markets for TEPs: a change in the emission cap, and an enlargement of the market to new comers.

4.1 Changing the emission cap

A fundamental feature of the TEP-market is the fact that a global emission cap is assigned to the economy. The conventional wisdom about cap-and-trade markets is that a strengthening of the global emission cap unambiguously leads to an increase in the permit price. As a consequence, the energy costs for firms should also increase.

Does this still hold under strategic taxation? The following proposition addresses this question.

Proposition 2 *Strengthening the global emission cap always increases the energy cost, but not necessarily the permit price. In fact,*

(i) *if the regulators are 'revenue-oriented', then energy taxes decrease and the permit price increases,*

(ii) *if the regulators are 'firm-oriented', then energy subsidies decrease and the effect on permit price is ambiguous,*

(iii) *when grandfathering increases, both effects are amplified.*

Proof. Given that each firm consumes $\bar{E}/N$, decreasing this value must be accompanied by an increase in the regulated cost of energy, by (1). The assumption that $\eta_c(p_c)$ is increasing in p_c ensures that taxes decrease if they are positive, and increase otherwise. Since $\hat{p} = 1 + \hat{\rho} + \hat{t}$, when taxes increase, $\hat{p}$ can increase only if $\hat{\rho}$ increases. Straightforward derivation of (8) shows that when α increases, equilibrium taxes depend more on the tax base. ■

This Proposition partially explains the evidence in Figure 1, which shows that the average tax level follows the total number of permits traded in the market. This evidence should be taken with caution, given the relatively short period that elapsed after the implementation of the EU-ETS.

When the emission cap becomes more stringent, firms in each country consume less permits in equilibrium, so its price must increase. Given that the semi-elasticity of permit demand is increasing, the permit demand is now more sensitive to tax changes, hence taxation (or subsidisation, when $\gamma > 1$) of energy is discouraged via the permit-leakage effect. When tax rates are positive, the permit price increases over and above what it would without strategic energy taxation: our setup entails an amplification of the effect of permit supply on its price. The effect of grandfathering is a result of its impact on the perceived importing position of the country: it discourages taxation for firm-oriented regulators and encourages taxation (i.e., lower subsidies) for firm-oriented ones.

4.2 Adding new countries

Let us now turn to an enlargement of the TEP-market. This is not a mere abstraction in our setting, since we are dealing with a market which is implemented amongst a set of countries and, logically countries outside this market may decide to join at some point. This actually happened with the ETS on the occasion of the EU enlargement. We neutralize the tax base effect by supposing that each new country receives exactly the TEP-endowment of the existing ones. Naturally, if the countries' TEP-endowment decreases, one may apply a two-step reasoning whereby, firstly, new countries join the market and then the market becomes more stringent, as analyzed in Proposition 2.

Proposition 3 *Suppose the number of countries increases and each country's permit endowment is kept constant. Then, the energy cost does not change, but the following holds:*

(i) *if the regulator is 'revenue-oriented', energy taxes decrease and the permit price increases,*

(ii) *if the regulator is 'firm-oriented', energy subsidies decrease and the permit price decreases,*

(iii) *increasing grandfathering leads to a smaller variation in taxes and permit price and, with full auctioning, the number of countries does not impact energy taxes and permit price.*

Proof. Straightforward derivation of (8) shows that $\frac{d\hat{t}}{dN} \leq 0$ whenever $\gamma \leq 1$. Since firm's energy consumption does not change, the regulated cost of energy must be kept constant, by (1). The fact that $\hat{p} = 1 + \hat{\rho} + \hat{t}$ implies that $\hat{\rho}$ varies in the opposite direction of $\hat{t}$. Finally, letting $\alpha = 0$, (8) boils down to

$$\hat{t} = \frac{1}{\hat{\eta}}(1 - \gamma)$$

which does not depend on N. ■

In order to understand this result, let us look at the two extreme cases of full grandfathering and no grandfathering. When all permits are given to the firms for free ($\alpha = 1$), the *perceived importing position* is equal to zero, and the only effect of increasing N stems from the fact that the weight of each country on the international TEP market decreases, hence the permit-leakage effect becomes stronger because the TEP price absorbs a smaller proportion of tax increases. Indeed, in the symmetric equilibrium we have that

$$\frac{d\hat{e}_c}{d\hat{p}_c} = e'_c \left(1 - \frac{1}{N}\right).$$

Hence, countries optimally respond by taxing (or subsidizing) less because their tax bases are more responsive to their tax choices.

Now let us look at the case where all permits are auctioned ($\alpha = 0$). The permit-leakage effect is still the same. Tax revenue increases by 1, the direct impact of the tax, and auction revenue decreases by $-1/N$, because ρ decreases. On the other hand, the firm's cost increases by 1, the direct impact of the tax, and decreases by $-1/N$ because ρ decreases and so does TEP cost. Hence, the effect of the tax increase is everywhere proportional to $1 - (1/N)$ and the market power of the country no longer matters.

5 The creation of the TEP market

Having understood the interplay between TEP-markets and energy taxation, we now turn to the analysis of the likely effects of introducing a TEP-market on a previously unregulated economy. In the absence of a TEP-market, the optimal energy consumption by the firms is implicitly given by $-C_f'(e_c) = 1 + t_c$. Countries maximize (3), with $\rho = \bar{e}_c = 0$. Their first-order condition is then

$$(1-\gamma)e_c(t_c) + t_c \frac{de_c(t_c)}{dt_c} = 0. \tag{9}$$

Using the fact that, in the absence of the TEP-market, $de_c/dt_c = de_c/dp_c = e_c'$, the autarkic energy tax t_c^a is thus given by

$$t_c^a = t^a = (1-\gamma)\frac{1}{\eta^a}, \tag{10}$$

where η^a denotes the semi-elasticity of permit demand when the price of energy is given by $(1+t^a)$.

Let us now assume that a non-constraining TEP-market enters into force. By 'non-constraining' we mean that each country is endowed with a number of permits equal to its firm's emissions in the absence of permits market. One could expect no changes in the economy, because the emission cap is non-binding. In fact, even this neutral form of emission market will change energy taxation, just because introducing the market creates mobility of the tax base (which is immobile under autarky). This result is provided in the following proposition.

Proposition 4 *Suppose a non-constraining TEP-market is introduced.Then, the energy cost remains constant but the following effects occur:*

(i) *'revenue-oriented' regulators increase their energy tax, whereas 'firm-oriented' regulators increase their energy subsidy,*

(ii) *increasing the share of grandfathering amplifies the above effects,*

(iii) *with full auctioning, energy taxes remain unchanged.*

Proof. Using (8) and (10), and the fact that the market is non constraining, it is straightforward to obtain $\frac{\hat{t}}{t^a} = (1-\frac{1-\alpha}{N})/(1-\frac{1}{N}) \geq 1$, which is equal to 1 when $\alpha = 0$. ■

The preliminary evidence on Figure 1 suggests that the tax level has increased with the introduction of the EU-ETS in 2005, confirming the result in this proposition.[15]

Introducing a non-constraining TEP-market keeps the tax base at the same level. However, the responsiveness of the tax base to the tax rate declines, thanks to the

[15]Indeed, the average tax level before (resp., after) the introduction of EU-ETS is 177.9 (resp., 194.16) and the the two values are significantly different at the 1% confidence level. Again, this preliminary evidence is to be taken cautiously, given the very short number of observations.

partial absorption of the tax increase by the TEP-price. In other words, the cost of energy varies one-to-one with the tax rate in autarky, while it varies less under a TEP-market. This leads countries to increase their taxes (or subsidies). The so-called run to the bottom result of the tax competition literature is sometimes interpreted as a decrease in the tax rate when borders are open, *i.e.*, when the tax base becomes mobile. Proposition 4 shows that the exact opposite happens in our setting with revenue-oriented regulators.

As auctioning permits is a disincentive to tax, the tax increase following the introduction of the market is greater when grandfathering is more important. In the absence of grandfathering, we already know from Proposition 3 that the market power of the country does not matter for tax setting, hence the introduction of the market does not change energy taxes.

6 Asymmetric permit endowments

In this last section we shall relax the assumption of symmetric permit endowments to grasp the effects of permits allocation on energy taxes in a general way. This will allow us to obtain two more results, the first related to country taxation, the second related to the efficiency of the TEP-market.

6.1 Permit endowments and energy taxes

Let us pick up two countries from the economy, denoted by 'A' and 'B'.

Proposition 5 *If the permit endowment of firms in country A is lower than in country B, and if taxes are strategic complements, then country A sets a higher tax than country B. Moreover, a TEP-importing country sets a higher energy tax than a TEP-exporting one.*

Proof. See Appendix. ■

The intuition behind Proposition 5 rests on the *terms of trade* effect, which is an incentive to tax for a (perceived) importer, and a disincentive to tax for a (perceived) exporter. Since the country with the small endowment will (at a given tax rate) either import more, or export less, it has an incentive to set a higher tax rate.

According to Proposition 5, countries ranking in terms of energy taxes is the inverse of the ranking in permit endowments. Following the same token as above, we can also answer a closely related question, namely, how does the equilibrium change if we switch the endowments of two different countries? The following corollary provides the answer.

Corollary 1 *Suppose a reallocation of TEP endowments such that country A gets more permits and country B less, the total amount being kept unchanged. Then the energy tax decreases in country A and increases in country B, if taxes are strategic complements.*

6.2 Cost-inefficiency of the market for tradable permits

In setting up a market for permits, the aim is to curb pollution in a *cost-efficient* way. This property of TEPs is widely put forward in the literature (since Montgomery, 1972) and generally used as an argument by its advocates (see *e.g.* IEA, 2006). This property, stated without strategic fiscal interactions, is questioned in our much more realistic setting.

The allocation of pollution emission is *cost-efficient* if, for a given quantity of aggregate pollution, the aggregate emission abatement cost is minimized. Formally, a cost-efficient pollution abatement is the solution of the following problem

$$\min_{\{e_1,\dots,e_N\}} \quad \sum_{c=1}^{N} C(e_c) \qquad \text{s.t.} \quad \sum_{c=1}^{N} e_c = \bar{E}.$$

Hence, cost-efficiency is attained when $C'(e_c) = \kappa$, $\forall c$, where κ is a finite negative number. We show that, in the case of an international market with fiscal spillovers, this property does not hold anymore.[16] Proposition 5 shows that energy taxes generically differ when countries have different permit endowments. Then follows Corollary 2.

Corollary 2 *When countries set energy taxes non-cooperatively, equilibrium taxes are generically different. Hence, an international market for tradable emission permits is not cost-efficient.*

This result shows that the efficiency gains of introducing a market are not realized if the power to tax energy inputs is left to the national initiative. This is a worrisome result, in that, as stressed in the introduction, empirical evidence confirms strong cross-country differences in energy taxation, which may be taken as evidence of asymmetries amongst firms locating in each country. This asymmetry will likely lead countries to set different taxes under the international TEP-market. Moreover, the relative importance of energy tax revenue in some countries makes it unlikely that all countries would be ready to give up their fiscal autonomy in this matter. Indeed, early attempts to coordinate carbon taxes in the European Union have been blocked by political reasons (Skjærseth and Wettestad, 2009).

What does this result imply for the desirability of a TEP-market? There is one obvious way to overcome the inefficiency: adjust TEP endowment in such a way that countries set the same energy tax. In a setting of symmetric countries, this amounts to symmetric TEP endowments. In a more general setting where firms have different abatement cost curves, it suffices to endow each country with the exact TEP demand of its firm or firms, in a way that makes the *perceived* net importing position equal across countries. A related question is whether the TEP-market improves upon the autarkic situation. Naturally, if the environmental damage is taken into account, and there is over-pollution in autarky, then one may argue that it is better to achieve a

[16] Indeed, suppose that there are no energy taxes, *i.e.*, $t_c = 0$ in all countries. Then the choice of the energy input by the firms is such that $-C'(e_c) = 1 + \rho$ and cost-efficiency is achieved.

reduction in pollution, even if not in a cost effective manner. This is not, however, the case in our setting. If one introduces a non-constraining market, as in Proposition 4, and if we allow the TEP-endowments to differ across countries, as in Proposition 5, then the abatement costs become asymmetric across countries. Indeed, the effect of introducing a market with asymmetric endowments is to introduce asymmetry in a previously symmetric world where marginal abatement costs were equated via tax-regulations. While this last result is arguably particular to our setting, the previous one that adjusting the allocation of permits across countries can be used to achieve efficiency (or, at least, decrease inefficiency) carries through to an asymmetric country setting.

It is important to notice that country asymmetry *per se* does not imply asymmetric taxation, rather it is the non-cooperative behavior that does so. If countries were to cooperate to minimize total abatement cost they would set equal tax rates.

7 Conclusion

With the background of the establishment of several environmental agreements at the international level we analyze the interaction between an international market for tradable polluting permits and national energy taxes. Because the market for tradable emission permits introduces a mobile tax base between countries (the polluting permits themselves), it creates room for fiscal competition.

We suppose that each country delegates energy tax choices to a national regular with the double mandate of obtaining fiscal and auction revenue, on the one hand, while not jeopardizing the representative firm's competitiveness, on the other hand. That is, it maximizes a weighted sum of fiscal and auction revenue and (the negative of) firm's costs, and we keep our analysis general enough that the regulator may attach a higher weight to either one. Our analysis highlights the effects that drive tax choices: the *tax base*, the *permit leakage* and the *terms of trade* effects. The analysis of the interplay between these effects allows us to characterize how equilibrium energy taxes depend on the TEP-market design, i.e. the total amount of permits issued, the number of countries which join the market, the allocation of permits across countries, and the share of this endowment which is given to the firms (grandfathering) instead of auctioned. We also look at the impact of introducing the market on a previously autarkic world.

Revenue-oriented (i.e., attaching a higher weight to the fiscal and auction revenue) regulators tax energy, while firm-oriented regulators subsidize energy. We show that the effect on taxes depends on the relative importance of the two mandates to the regulator. Increasing the restrictiveness of the market (i.e. decreasing the emission cap) leads lower energy taxes or lower energy subsidies, depending on the dominant mandate of the regulator. The same effect is obtained by adding new countries without increasing the stringency of the emission cap. The introduction of the market has the opposite effect on energy taxation, i.e., countries increase their energy taxes or their subsidies, because the TEP price partially absorbs tax increases, thus decreasing the permit leakage effect. Introducing asymmetry in the allocation of permits across countries, we are able to show that the permit-richest country sets a lower energy tax. Interestingly, the very preliminary evidence regarding energy taxation and the introduction of the EU-ETS market can be explained by our results.

The way in which the permits are allocated to the firms – i.e., auctioned or grandfathered – changes the incentives to tax or subsidize. In a nutshell, more grandfathering decreases the importing position of the firms and decreases the exporting position of the country in the permit market. A firm-oriented regulator attaches more importance to the former effect, while a revenue-oriented one attaches more importance to the latter. Hence, increased grandfathering decreases the perceived importing position of a firm-oriented regulator, thus discouraging taxation, and increases that of a revenue-oriented regulator, thus encouraging taxation (i.e., decreasing the subsidy).

Considering strategic taxation leads us to question one common argument in favor of tradable permits, namely, that it achieves emission reduction in a cost-efficient way. We have shown that TEP-markets are cost effective only if they are accompanied by a tax harmonization policy. Another widely accepted result of perfectly competitive TEP markets which does not hold in our setup is that the way in which the permits are allocated is neutral with respect to the market outcomes. Given that the regulators attach different weights to the representative firm's production costs and fiscal and auction revenue, whether one permit is auctioned or given away to the firm for free changes the incentives to tax energy and thus the equilibrium in the permit market.

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Appendix

The following lemma states the existence and uniqueness of the equilibrium.

Lemma 1 *There exists a unique permit price* $\rho(\mathbf{t}, \bar{E})$ *that clears the market. Furthermore, assuming that* $\bar{E} < \sum_{c=1}^{N} e_c(1+\bar{t})$, *the equilibrium permit price is strictly positive.*

Proof of Lemma 1 Recall the equilibrium condition on the market for TEPs (4). Since the left-hand side of (4) is strictly decreasing in ρ, for each tax vector $\mathbf{t} = \{t_1, \ldots t_N\}$, and the global permits supply $\bar{E}$ being given, there exists a unique permit price $\rho(\mathbf{t}, \bar{E})$ satisfying (4). To see that $\rho(\mathbf{t}, \bar{E}) > 0$, notice that

$$\frac{d\rho(\mathbf{t}, \bar{E})}{dt_c} = \rho_{t_c} \quad = \quad -\frac{e'_c(p_c)}{\sum_{j=1}^{N} e'_j(p_j)} < 0 \tag{11}$$

hence the lowest equilibrium $\rho(\mathbf{t}, \bar{E})$ arises when $t_c = \bar{t}$, $\forall c$. This fact, together with the assumption that $\sum_{c=1}^{N} e_c(\bar{t}) > \bar{E}$ ensures $\rho(\mathbf{t}, \bar{E}) > 0$ when $t_c = \bar{t}$, $\forall c$, hence it must also be positive for any other possible tax vector.□

Proof of Proposition 5

(i) For any two countries a and b and taking the set $\hat{t}_{i \notin \{a,b\}} = \left\{\hat{t}_i,\, i \notin \{a, b\}\right\}$ as given, we may rewrite (6) for countries a and b

$$\Phi(\hat{t}_a, \bar{e}_a, \hat{t}_b, \hat{t}_{i\notin\{a,b\}}) = (1-\gamma)\hat{e}_a + \hat{t}_a\hat{e}'_a(1+\hat{\rho}_{t_a}) - \hat{\rho}_{t_a}\left(\gamma(\hat{e}_a - \alpha\bar{e}_a) - (1-\alpha)\bar{e}_a\right) = 0$$
$$\Phi(\hat{t}_b, \bar{e}_b, \hat{t}_a, \hat{t}_{i\notin\{a,b\}}) = (1-\gamma)\hat{e}_b + \hat{t}_b\hat{e}'_b(1+\hat{\rho}_{t_b}) - \hat{\rho}_{t_b}\left(\gamma(\hat{e}_b - \alpha\bar{e}_b) - (1-\alpha)\bar{e}_b\right) = 0$$

Now take $\bar{e}_a < \bar{e}_b$, and suppose that $\hat{t}_a < \hat{t}_b$. Then, we have that $\hat{e}_a > \hat{e}_b$ and, by definition of the Nash Equilibrium,$\Phi(\hat{t}_a, \bar{E}_a, \hat{t}_b, \hat{t}_{i\notin\{a,b\}}) = 0$. Now using, successively, concavity of the payoff functions, strategic complementarity, and, lastly, the fact that $\partial\Phi(\cdot)/\partial\bar{e}_c < 0$ we may write

$$0 = \Phi(\hat{t}_a, \bar{e}_a, \hat{t}_b, \hat{t}_{i\notin\{a,b\}}) > \Phi(\hat{t}_b, \bar{e}_a, \hat{t}_b, \hat{t}_{i\notin\{a,b\}}) >$$
$$\Phi(\hat{t}_b, \bar{e}_a, \hat{t}_a, \hat{t}_{i\notin\{a,b\}}) > \Phi(\hat{t}_b, \bar{e}_b, \hat{t}_a, \hat{t}_{i\notin\{a,b\}}) = 0$$

And a contradiction is reached.□

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